HQ. GRANT
IN-91-CR
169986
P-43

REPORT

TO THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ANNUAL STATUS REPORT
(Includes Semiannual Status Report #10)

for

GRANT NAGW-533

LABORATORY EVALUATION AND APPLICATION OF MICROWAVE ABSORPTION PROPERTIES UNDER SIMULATED CONDITIONS FOR PLANETARY ATMOSPHERES

Paul G. Steffes, Principal Investigator

February 1, 1988 through January 31, 1989

Submitted by

Professor Paul G. Steffes
School of Electrical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332-0250
(404) 894-3128

(NASA-CR-183327) LABORATORY EVALUATION AND APPLICATION OF MICROWAVE ABSORPTION PROPERTIES UNDER SIMULATED CONDITIONS FOR PLANETARY ATMOSPHERES Semiannual Status Report No. 10, 1 Feb. 1988 - 31 Jan. 1989

N89-15843

Unclas
G3/91 0169986

TABLE OF CONTENTS

I. INTRODUCTION AND SUMMARY

Radio absorptivity data for planetary atmospheres obtained from spacecraft radio occultation experiments and earth-based radio astronomical observations can be used to infer abundances of microwave absorbing atmospheric constituents in those atmospheres, as long as reliable information regarding the microwave absorbing properties of potential constituents is available. The use of theoretically-derived microwave absorption properties for such atmospheric constituents, or laboratory measurements of such properties under environmental conditions which are significantly different than those of the planetary atmosphere being studied, often leads to significant misinterpretation of available opacity data. Results obtained for the microwave opacity from gaseous H_2SO_4 under simulated Venus conditions, during the first two years of Grant NAGW-533, showed that not only was the opacity from H_2SO_4 much greater than theoretically predicted, but that its frequency (wavelength) dependence was far different than that theoretically predicted (Steffes, 1985 and Steffes, 1986). Measurements made by Steffes and Jenkins (1987), during the third year of Grant NAGW-533, have shown that the microwave opacity of gaseous ammonia (NH_3) under simulated Jovian conditions did indeed agree with theoretical predictions to within experimental accuracy at wavelengths longward of 1.3 cm. Work performed during the fourth year of Grant NAGW-533 (February 1, 1987 through January 31, 1988) and continuing on into this current grant year (February 1, 1988 through January 31, 1989) has shown that laboratory measurements of the millimeter-wave opacity of ammonia between 7.5 mm and 9.3 mm requires a different lineshape to be used in the theoretical prediction for millimeter-wave ammonia opacity than had been previously used (see Joiner et al., 1988). The recognition of the need to make such

laboratory measurements of simulated planetary atmospheres over a range of temperatures and pressures which correspond to the altitudes probed by both radio occultation experiments and radio astronomical observations, and over a range of frequencies which correspond to those used in both radio occultation experiments and radio astronomical observations, has led to the development of a facility at Georgia Tech which is capable of making such measurements. It has been the goal of this investigation to conduct such measurements and to apply the results to a wide range of planetary observations, both spacecraft and earth-based, in order to determine the identity and abundance profiles of constituents in those planetary atmospheres.

The key activity for this grant year has continued to be laboratory measurements of the microwave and millimeter-wave properties of the simulated atmospheres of the outer planets and their satellites. As described in the previous Annual Status Report for Grant NAGW-533 (February 1, 1987 through January 31, 1988), initial laboratory measurements of the millimeter-wave opacity of gaseous ammonia (NH_3) in a hydrogen/helium (H_2/He) atmosphere, under simulated conditions for the outer planets were begun in 1987. These measurements were conducted at frequencies from 32 to 40 GHz (wavelengths from 7.5 to 9.3 mm). It has been found by some (e.g., de Pater and Massie, 1985) that the observed millimeter-wave emission from Jupiter is inconsistent with the millimeter-wave absorption spectrum predicted using the modified Ben-Reuven lineshape for ammonia. In order to investigate this, we developed a Fabry-Perot spectrometer system capable of operation from 32 to 41 GHz. This system has been used at pressures up to 2 Bars and temperatures as low as 150 K, which corresponds closely to the conditions at altitudes in the Jovian atmosphere most responsible for the observed millimeter-wave absorption.

A complete description of the millimeter-wave spectrometer is given in Section II.

Initially, we used this spectrometer to complete laboratory measurements of the 7.5 to 9.3 mm absorption spectrum of ammonia. The results of these measurements were substantive in that they suggested the possibility that neither the modified Ben-Reuven lineshape nor the Van Vleck-Weisskopf lineshape best described the 7.5 to 9.3 mm (32 to 40 GHz) absorption from gaseous NH_3 under simulated Jovian conditions. However, because of the large error bars for these initial measurements, it was not possible to determine the specific absorption spectrum. In order to resolve this uncertainty, we have found that it is desirable to characterize the opacity of ammonia to an accuracy of ±20%. For our initial measurements, accuracies of no better than ±60% were achieved (see Joiner et al., 1987). Thus, we devoted a great deal of effort during the first half of this current grant year to improve the sensitivity of our 7.5 to 9.3 mm spectrometer system, as described in Section II. The effect of this improvement can be seen in the laboratory results described in Section IV.

Since larger variations from theoretically-derived opacity values were expected at shorter millimeter-wavelengths (see de Pater and Massie, 1985), we began (in the second half of this grant year) laboratory measurements at wavelengths near 3.2 mm (94 GHz), where a large number of observations of the emission from the outer planets have been made. A description of this new system is presented in Section II. A better knowledge of the millimeter-wave absorption properties of NH_3 is essential, not only to help better characterize the distribution and abundance of ammonia at high levels in Jovian atmospheres, but to make it possible to resolve the contributions from other absorbing constituents such as H_2S (see Bezard et al., 1983).

In some cases, new observations or experiments have been suggested by the results of our laboratory measurements. For example, this facility was initially developed, and then operated, in order to evaluate the microwave absorbing properties of gaseous sulfuric acid (H_2SO_4) under Venus atmospheric conditions. The results, obtained at 13.4 cm and 3.6 cm wavelengths, were applied to measurements from Mariner 5, Mariner 10, and early Pioneer-Venus Radio Occultation experiments, to determine abundances of gaseous sulfuric acid in the Venus atmosphere, with accuracies exceeding those achieved with in-situ instruments (Steffes, 1985). Further laboratory measurements also suggested that a substantial variation in the Venus microwave emission, related to the abundance of gaseous sulfuric acid, might exist near the 2.2 cm wavelength. Since no observations of the Venus emission at this wavelength had ever been published, we conducted observations of Venus using the 140-foot NRAO telescope and the 64-meter DSN/Goldstone antenna in April 1987 to not only search for the presence of the predicted feature, but to use such a feature to determine a planet-wide average for sulfuric acid vapor abundance below the main cloud layer. The results of this observation were substantial in that they not only placed limits on the abundance and spatial distribution of gaseous H_2SO_4 and SO_2, but they also suggested some limits to long term temporal variations for the abundance of these two gases. During the first half of this current grant year, we have completed calibration and interpretive studies on the data from these observations and have submitted a paper entitled, "Observations of the Microwave Emission of Venus from 1.3 to 3.6 cm," by P. G. Steffes, M. J. Klein, and J. M. Jenkins, to the journal Icarus.

Another important tool for evaluating potential spatial and temporal variations in abundance and distribution of gaseous H_2SO_4 is the reduction and analysis of recently obtained Pioneer-Venus radio occultation measurements. The 13 cm microwave absorptivity profiles, which can be obtained from the radio occultation data, are closely related to the abundance profiles for gaseous H_2SO_4. Starting in June, we began the reduction of the 1986-87 Pioneer-Venus radio occultation measurements (working at JPL with support from the Pioneer-Venus Guest Investigator Program) in order to obtain the needed 13 cm microwave absorptivity profiles. This reduction effort, and its potential results, are discussed in Section V of this report.

Over the next nine months of Grant NAGW-533, we intend to complete our laboratory analysis of the millimeter-wave absorption from gaseous NH_3 under simulated Jovian conditions, by completing our laboratory studies at 3.2 mm (94 GHz). We will then develop a formulation which accurately predicts the opacity from gaseous ammonia in a Jovian-type atmosphere over the entire 3 mm to 20 cm wavelength range (frequencies from 1.5 to 100 GHz). With such a formulation at our disposal, we will then develop models for microwave and millimeter-wave emission from the Jovian planets and adjust aommonia abundance profiles so as the match the emission spectrum observed from earth-based radio telescopes. We may even be able to take advantage of the availability of several millimeter-wave radio telescope arrays in order to make observations from which we could develop localized ammonia abundance profiles over the entire disk of one or more Jovian planets. Likewise, we will continue to take advantage of the availability of profiles of the 13 cm absorptivity in the Venus atmosphere, which we are developing as part of the Pioneer-Venus Guest Investigator Program. These profiles, which are related to the distribution

of gaseous H_2SO_4 will be invaluable for characterizing the spatial and temporal variabilities of H_2SO_4 in the Venus atmosphere. Finally, we will complete designs for laboratory instrumentation which will allow us to measure the microwave and millimeter-wave properties of liquids and solids under simulated planetary conditions. A more complete discussion of this proposed future activity is included in the accompanying proposal to NASA entitled, "Laboratory Evaluation and Application of Microwave Absorption Properties under Simulated Conditions for Planetary Atmospheres."

II. THE GEORGIA TECH RADIO ASTRONOMY AND PROPAGATION (R.A.P.) FACILITY

The basic configuration of the planetary atmospheres simulator developed at Georgia Tech for use in measurement of the microwave absorptivity of gases under simulated conditions for planetary atmospheres is described at length in the previous Annual Status Report(s) for Grant NAGW-533. It is also discussed at length in Steffes (1986) and Steffes and Jenkins (1987). The most recent addition to the Georgia Tech Radio Astronomy and Propagation Facility have been Fabry-Perot type resonators capable of operation between 30 and 41 GHz and between 93 and 95 GHz. As shown in Figure 1, the Ka-band resonator (32-40 GHz) consists of two gold plated mirrors (one with a flat surface, and one with a parabolic surface) separated by a distance of about 20 cm. The mirrors are contained in a T-shaped glass pipe which serves as a pressure vessel capable of withstanding over 2 atm of pressure. Each of the three open ends of the pipe is sealed with an O-ring sandwiched between the lip of the glass and a flat brass plate which is bolted to an inner flange. Electromagnetic energy is coupled both to and from the resonator (which operates as a bandpass filter) by twin irises located on the surface of the

flat mirror. Two sections of WR-28 waveguide which are attached to the irises pass through the brass plate to the exterior of the pressure vessel. The end of each waveguide section is pressure-sealed by a rectangular piece of mica which is held in place by a mixture of rosin and beeswax. As shown in Figure 2, one of these ends is connected to the sweep oscillator through a waveguide section. A Ka-band (26-40 GHz) mixer is attached to the other section of waveguide and is coupled to the high resolution spectrum analyzer through a calibrated section of coaxial cable. The entire resonator, including its glass pressure envelope, is placed in the temperature chamber, which is a low-temperature freezer capable of operation down to 150 K. A network of stainless steel tubing and valves connects other components such as gas storage tanks, vacuum gauges, the pressure gauge, and the vacuum pump to the resonator assembly, so that each component may be isolated from the system as necessary. When properly secured, the system is capable of containing up to two atmospheres of pressure without detectable leakage.

In order to achieve a better system sensitivity, which corresponds to a higher "Q" or quality factor for the Fabry-Perot resonator (see Section III), all losses in the resonator must be minimized, since the quality factor is defined as 2π times the ratio of the average energy stored in the resonator to the energy lost (per cycle) in the resonator. There are three sources of loss which typically affect a Fabry-Perot resonator (Collin, 1966):

(1) Resistive losses on the surfaces of the mirrors.

(2) Coupling losses due to the energy coupling out of the resonator through the irises on the flat-surfaced mirror.

(3) Diffraction losses around the sides of the mirror.

For previous measurements made at frequencies below 22 GHz (wavelengths longer than 1.35 cm), it was found that the resistive losses were predominant. This was because the measurements were conducted using cylindrical resonators, for which no diffraction losses existed. (See Steffes and Jenkins, 1987). Also, coupling losses were held to a minimum by using very small coupling loops and irises. The predominance of the resistive losses in the cylindrical resonators was demonstrated when such resonators were cooled to 193 K in the atmospheric simulator. Significant improvement in the quality factor of the resonators were observed when compared with their room temperature values. This was consistent with the expected reduction in the resistive losses at lower temperatures.

When the newer, higher frequency (32 to 40 GHz) Fabry-Perot resonator (Figure 1) was first cooled from room temperature down to 203 K for tests under simulated Jovian conditions, its quality factor appeared to worsen rather than improve. Initially, it was thought that this might have been caused by separation of the gold plating on the mirror surfaces from the back-structure (which had been machined from aluminum) due to differential thermal contraction. As a result, new mirrors were machined (to high tolerance) from brass, and then were plated with titanium and then gold, to assure no separation would occur. The performance of the new mirrors was only marginally better when installed in the resonator. Computation of the resistive losses from the mirrors showed that, in the absence of all other losses, the Q of our Fabry-Perot resonator should be on the order of 250,000; whereas its actual Q was on the order of 10,000. Therefore, it became clear that either coupling losses or diffraction losses were the limiting factor in its performance, and that even the introduction of high-temperature superconducting material would

not significantly improve the sensitivity of the system. (Note, however, that we are still studying the possibility of using high temperature superconductors in our lower frequency, cylindrical resonators in order to obtain increased sensitivity at frequencies below 22 GHz.)

In order to further improve the quality factor of the 32 to 40 GHz system, some additional improvements were made. First, adjustable irises were developed so that the smallest possible coupling losses would occur, while still allowing sufficient signal coupling in and out of the resonator so as to make accurate absorptivity measurements. Since the irises are actually circular holes which are placed near the center of the flat-surfaced mirror, adjustment of their sizes is difficult. However, two small metal sheets with V-shaped cuts were placed immediately behind each iris in an area where the mirror surface thickness is very small. The two sheets could be moved together or apart so as to adjust the effective size, and therefore the coupling, of each iris. Even when adjusted for minimal coupling, however, the resonator Q was only slightly improved, suggesting that diffraction losses were the major limiting factor to system sensitivity.

Diffraction losses occur due to energy being lost around the edges of the mirrors. These losses can be minimized by assuring that both mirrors are oriented directly toward each other (i.e., the centerlines for each mirror, which are orthogonal to the planes of each mirror at their centerpoints, must be colinear). Since the positioning of the mirrors can vary with temperature, due to thermal contraction or expansion of metallic mounting structures, the temperature dependence of the quality factor which has been observed is consistent with a system which is limited by diffraction losses.

Two approaches can be used to minimize diffraction losses. The first involves precise pointing of the mirrors. This was accomplished by directing the beam of a helium-neon laser through the input waveguide and iris and into the resonator. Mirror positioner screws could then be adjusted so that the reflected beam focused precisely on the output iris. Since the parabolic mirror has a precisely defined focus, adjustment of its exact position is far more critical than that of the flat mirror. The second technique for reducing diffraction loss involves the use of larger mirrors in the resonator. However, because of size limitations set by our pressure vessel, we are unable to significantly increase the size of the mirrors in our system.

Overall, our efforts during the first half of this grant year at improving the quality factor of our 32 to 40 Ghz Fabry-Perot resonator were successful, but in themselves were not enough to provide the needed increase in system sensitivity. However, since absorptivity is measured by monitoring the <u>change</u> in the quality factor of the resonator which is caused by the absorbing gas mixture, improvements in our measurement technique, described in Section III, have allowed us to achieve the required system sensitivity.

In the second half of this grant year, we implemented a similar system for operation around 94 GHz (3.2 mm). As shown in Figure 3, the 94 GHz resonator resembles the Ka-band Fabry-Perot resonator in that it consists of two gold plate mirrors, one with a flat surface and one with a parabolic surface. However, the 94 GHz resonator is significantly different in that the flat mirror has a much smaller radius than the parabolic mirror, and the focal length of the parabolic mirror is much shorter, resulting in "tighter" focusing. Mechanically, the 94 GHz resonator is superior in that the parabolic mirror rests on two support arms and can be adjusted in distance from

the flat mirror without disturbing the other angular adjustments. The result has been a resonator with a quality factor (Q) of about 30,000.

The 94 GHz system (Figure 4) functions in the same fashion as does the Ka-band system in that changes in the Q of the Fabry-Perot resonator are monitored as lossy gas mixtures are introduced into the pressure vessel. However, because of the extremely high frequency of operation, costly millimeter-wave components (e.g., signal sources, waveguides, and mixers) are required. Fortunately, such a resource of millimeter-wave equipment exists at Georgia Tech within the Georgia Tech Research Institute (GTRI) and has been made available to us for these experiments. Figure 4, shows a W-band (75-110 GHz) sweep oscillator whose signal is fed into the Fabry-Perot resonator via an isolator, so as to provide a constant impedance both for the backward wave oscillator (BWO) tube in the sweeper and for the resonator. The resonator output at 94 GHz is then down-converted to around 1.55 GHz using a harmonic mixer which employs the tenth harmonic of a stabilized 9.24 GHz oscillator. The 1.5 GHz signal is then fed to the high-resolution spectrum analyzer by which the bandwidth (and, therefore, the Q) of the resonance can be measured. The pressurization systems for both systems are essentially identical.

III. EXPERIMENTAL APPROACH

The approach used to measure the microwave absorptivity of test gases in an H_2/He atmosphere is similar to that used previously by Steffes and Jenkins (1987) for simulated Jovian atmospheres. At frequencies between 32 and 40 GHz, the changes in the Q of the numerous resonances of the Fabry-Perot resonator (see Figure 2) are related to the absorptivity of the test gas mixture at these frequencies. Similarly, the changes in the Q of the single

94 GHz resonance are related to the absorptivity at that frequency. The changes in the Q of the resonances which are induced by the introduction of an absorbing gas mixture can be monitored by the high resolution microwave spectrum analyzer, since Q is simply the ratio of the cavity resonant frequency to its half-power bandwidth. For relatively low-loss gas mixtures, the relation between the absorptivity of the gas mixture and its effect on the Q of a resonance is straightforward:

$$\alpha \approx (Q_L^{-1} - Q_C^{-1})\pi/\lambda \tag{1}$$

where α is absorptivity of the gas mixture in Nepers km^{-1}. (Note, for example, that an attenuation constant or absorption coefficient or absorptivity of 1 Neper km^{-1} = 2 optical depths per km (or km^{-1}) = 8.686 dB km^{-1}, where the first notation is the natural form used in electrical engineering, the second is the usual form in physics and astronomy, and the third is the common (logarithmic) form. The third form is often used in order to avoid a possible factor-of-two ambiguity in meaning.) Q_L is the quality factor of the cavity resonator when the gas mixture is present, Q_C is the quality factor of the resonance in a vacuum, and λ is the wavelength (in km) of the test signal in the gas mixture.

In the first half of this grant year, we have made high accuracy measurements of the 7.5 to 9.3 mm absorption from gaseous ammonia (NH_3) in a 90% H_2/10% He atmosphere. at a temperature of 203 K. While even lower temperatures could be achieved, the need to avoid the risk of ammonia condensation kept our operating temperatures relatively high. As in the previous experiments, the bandwidth and center frequencies of each of several

resonances between 32 and 40 GHz were measured in a vacuum. Next, 28 torr of gaseous ammonia is added to the system. The pressure of the ammonia gas is measured with the high-accuracy thermocouple vacuum gauge, as shown in Figure 2.

In addition, the ammonia abundance can be monitored by measuring refractivity of the introduced gas. Since the index of refraction (relative to unity) at low pressure is proportional to the ammonia gas abundance, the ability of the system to accurately measure refractivity (through measurement of the frequency shift of resonances) can be used to infer the relative vapor abundance or pressure. Note that it is not yet possible to use this approach for the accurate determination of absolute NH_3 pressure since accurate refractivity data for the 7.3 to 10 mm wavelength range is not available. (In fact, by using our thermocouple vacuum gauge, we have made measurements of the density-normalized refractivity of gaseous ammonia at 39 GHz, and found it to be 6.1×10^{-17} N-units/molecule/cm^3, which is nearly 6 times the value at optical wavelengths.)

Next, 1.8 atm of hydrogen (H_2) and 0.2 atm of helium (He) are added to the chamber, bringing the total pressure to 2 atm. The bandwidth of each resonance is then measured and compared with its value when the chamber was evacuated in order to determine the absorptivity of the gas mixture at 2 atm total pressure. The total pressure is then reduced, by venting, to 1 atm, and the bandwidths are again measured. Finally, the pressure vessel is again evacuated and the bandwidths again measured so as to assure no variation of the Q's of the evacuated resonator has occurred. As with the previous measurements, the measured changes of bandwidths (Q's) can then be used to compute the absorptivity of the gas mixtures at each of the resonant frequencies.

This approach has the advantage that the same gas mixture is used for the absorptivity measurements at the various pressures. Thus, even though some small uncertainty may exist as to the mixing ratio of the initial mixture, the mixing ratios at all pressures are the same, and thus the uncertainty for any derived pressure dependence is due only to the accuracy limits of the absorptivity measurements, and not to uncertainty in the mixing ratio. (This assumes that the mixing ratio is small, so that foreign-gas broadening predominates, as is the case for our measurements.) Similarly, measurements of the frequency dependence of the absorptivity from the mixture would likewise be immune to any mixing ratio uncertainty, since foreign-gas broadening predominates.

For the measurements described, the amount of absorption being measured is extremely small. Thus, any errors in measurements of (or other changes in) the apparent bandwidth of the resonances, not caused by the absorbing gases, could lead to significant errors in the absorption measurement. The contribution of instrumental errors and noise-induced errors on such absorptivity measurements have been discussed at length in Steffes and Jenkins (1987). However, because our latest measurements represent such small percentage changes in bandwidth, another instrumental source of error which we refer to as dielectric loading becomes a concern.

As can be seen in Figure 2, the resonator, which operates as a bandpass filter, is connected to a signal source (the millimeter-wave sweep oscillator) and to a signal receiver (the high-resolution spectrum analyzer). The "Q" of the resonator, which is defined as the ratio of energy stored in the resonator to the energy lost per cycle, equals the ratio of resonant center frequency to resonance half-power bandwidth. It is not surprising, therefore, that the

stronger the coupling between the resonator and the spectrum analyzer or sweep oscillator, the lower will be the Q of the resonance, since more energy will be lost per cycle through the waveguides connecting the resonator to the spectrum analyzer and sweep oscillator. For this reason, we have always designed our resonators (both the coaxially-coupled cylindrical cavity resonators used below 25 GHz and the waveguide-coupled Fabry-Perot resonators used above 30 GHz) with minimal coupling, so as to maximize Q and to minimize the changes in Q that might result from changes in coupling that occur when gases are introduced into the resonators. It should be noted that these changes in coupling, which are due to the presence of the test gas mixtures, are not related to the absorptivity of the gases, but rather to the dielectric constant or permittivity of the test gas mixtures. (Hence, the term "dielectric loading.")

We have always strived to design the coupling elements of the resonators so that the changes in lossless test gas abundances (and resulting changes in dielectric constant) had little or no effect on the Q of the resonator as measured in the system. This has been no small feat in that slight imperfections in resonators, cables, coupling loops, or waveguides can make the apparent Q of the resonator appear to vary with the abundance of such lossless gases. It has now become a standard part of our experimental procedure to repeat absorption measurements for gas mixtures in which the absorbing gas is a minor constituent, <u>without the absorbing</u> gas present. For example, after measurements were made of the microwave and millimeter-wave absorption from ammonia as a minor constituent in an H_2/He atmosphere, measurements of the apparent absorption of the H_2/He atmosphere <u>without</u> the ammonia gas were made. Since, for the pressures and wavelengths involved, the H_2/He atmosphere is

essentially transparent, no absorption was expected. If any apparent absorption was detected, "dielectric loading," or a change in coupling due to the dielectric properties of the gases, was indicated.

Initially, if any evidence of dielectric loading existed, the experiments were terminated and the apparatus disassembled, including pressure seals. The cables and coupling loops were then readjusted, and the system reassembled and tested again. The entire procedure was repeated until the dielectric loading effect was eliminated or minimized. If some small variation in the resonant Q or bandwidth due to the presence of the non-absorbing gases still remained, it was added to the uncertainty or error bars for each experiment. More recently however, we have found that the effects of dielectric loading are additive, in that they add to the apparent changes of resonator bandwidth caused by the absorbing gases. Thus, as long as the effects of dielectric loading are not time variable, they can be removed by using the measured value of the Q of a resonance with the non-absorbing gases present (instead of the Q of the resonance in a vacuum) for the quantity Q_c in equation (3).

Another potential source of instrumental error which we have recently detected has to do with nonlinearities in the spectrum analyzer display. We have found that depending on the vertical position of the bandpass spectrum on the spectrum analyzer CRT display, the peak signal level (and, therefore, the apparent half-power bandwidth and resulting quality factor) of the resonator seems to vary slightly. This is due to nonlinearities in the CRT vertical deflection amplifier. We have minimized this potential error by always resetting the vertical position of the displayed spectrum to the same portion of the CRT screen.

As previously discussed, once a test gas mixture is formed in the pressure vessel, the same mixture is used for measurement of absorption at several frequencies and pressures. Thus, even though some uncertainty in absolute mixing ratio exists, the pressure and frequency dependences of the millimeter-wave absorption can be measured to high accuracy. However, in order to properly characterize the magnitude of the absorption, the ammonia mixing ratio must be known precisely. Using the high accuracy thermocouple vacuum gauge shown in Figure 2, the actual NH_3 mixing ratio can only be determined to an accuracy of ±20% of its value. (Note: This corresponds to (1.85 ± 0.37)% NH_3 volume mixing ratio.) However, since our required overall accuracy for the NH_3 absorptivity measurement is ±20%, this mixing ratio uncertainty is excessive. In order to reduce this uncertainty, we arranged for a local gas products supplier (Matheson Gas Products) to provide us with a pre-mixed hydrogen/helium/ammonia atmosphere which was analyzed with a mass spectrometer so that mixing ratio accuracies of better than 2% (i.e., (1.85 ± .04)%) were obtained. We have used this mixture (1.85% NH_3, 9.81% He, and 88.34% H_2) for the high accuracy absorptivity measurements which are required to accurately infer ammonia abundance from millimeter-wave opacity data for the Jovian planets.

This same "custom" gas mixture has been measured under the same conditions (total pressures of 1 and 2 Bars and temperature 203 K), using the same techniques, at a single resonance near 94 GHz (3.2 mm). However, because the absorptivity of ammonia is less at 3.2 mm than in the 7.5-9.3 mm wavelength range, the percentage accuracy of the measurements have been worse, even though the quality factor of the 3.2 mm resonator is higher. As a result, a second "custom" gas mixture has been obtained with an even higher

ammonia mixing ratio (5.07% NH_3. 85.56% H_2, 9.37% He). Because of the higher ammonia mixing ratio (and the need to avoid condensation), measurements of the 94 GHz absorptivity of this new mixture have been conducted at a slightly higher temperature (210 K) for total pressures of 1, 1.3, and 2 Bars.

IV. RESULTS OF LABORATORY MEASUREMENTS AND THEIR APPLICATION

Initial measurements of the 7.5 to 9.3 mm absorptivity from NH_3 in a hydrogen/helium atmosphere were conducted at 203 K as described in Section III, with an ammonia mixing ratio of 0.0186, at pressures of 1 and 2 Bars. An examination of these early experimental results revealed that because of large error bars, we could not determine whether the modified Ben-Reuven lineshape best described the absorption profile of gaseous ammonia shortward of 1 cm, as discussed in Sections I and II. As a result, we undertook higher accuracy measurements in the first half of this current grant year.

Results of measurements of the 32 to 40 GHz (7.5 to 9.3 mm) absorptivity of gaseous ammonia under simulated Jovian conditions (203 K) are shown in Figure 5. These measurements were made using a 88.3% hydrogen/9.81% helium atmosphere with a total pressure of 2 Bars. The ammonia mixing ratio was 0.0185. Triangular points represent measurements of gas mixtures formed using the thermocouple vacuum gauge (NH_3 mixing ratio accuracy = ±20% of its value) and the circular points represent measurements of the pre-mixed, analyzed gas mixture described in Section III. With this mixing ratio, temperatures as low as 190 K could have been used before saturation would have become a problem, but 203 K was used so as to be consistent with earlier measurements.

Also, shown in Figure 5 are solid lines which represent the theoretically-computed opacity using the Van Vleck-Weisskopf lineshape (upper line), the modified Ben-Reuven lineshape (middle line), and the Zhevakin-Naumov lineshape (lower line). The Van Vleck-Weisskopf calculation was performed using linewidths and line intensities as per Wrixon et al. (1971). The Ben-Reuven calculation was made as per Berge and Gulkis (1976), by employing a Ben-Reuven lineshape which has been modified so as to be consistent with the laboratory results of Morris and Parsons (1970), in which the 9.58 GHz absorption from NH_3 (in a high pressure H_2/He atmosphere) at room temperature was measured. The Zhevakin-Naumov calculation used the lineshape of Zhevakin and Naumov (1967) and linewidths and line intensities from Wrixon et al. (1971). These theoretical spectra were computed using generalized computer programs for which the partial pressures from H_2, He, and NH_3, as well as frequency and temperature, were adjustable variables. The values picked for these variables matched our experimental conditions.

Inspection of the results in Figure 5 shows that most of the measured data points lie nearest to the theoretically-derived absorptivity expression based on the Zhevakin-Naumov lineshape. This differs from our preliminary measurements which suggested that the ammonia opacity might actually exceed that indicated by the modified Ben-Reuven lineshape. Such results are not surprising, however, in that the accuracy of the new measurements is far greater than that from previous measurements. It is also noteworthy that other researchers, such as de Pater and Massie (1985), have found that in order to best explain the 1-10 mm Jupiter emission spectrum, a different sort of lineshape was needed to characterize the ammonia capacity. Likewise, previous laboratory measurements of NH_3 opacity at frequencies below 22 GHz

showed opacities slightly less than those indicated by the modified Ben-Reuven lineshape under the same conditions of temperature and pressure (Steffes and Jenkins, 1987). However, it has been noted by Spilker (private communication) that slight changes to the modified Ben-Reuven formulation can be made which make it more consistent with longer wavelength laboratory results, and make it essentially identical with the Zhevakin-Naumov formulation at frequencies between 32 and 40 GHz (see discussion below).

Our preliminary results at 94 GHz, shown in Figure 6, definitely favor the modified Ben-Reuven formalism. When the data points for opacity are compared with the theoretically-computed opacity using the Van Vleck-Weisskopf lineshape (upper line), the modified Ben-Reuven lineshape (middle line), and the Zhevakin-Naumov lineshape (lower line), it becomes clear that the modified Ben-Reuven lineshape best characterizes the opacity at 3.2 mm under the conditions of this measurement (Total Pressure: 2 Bars; Temperature: 213 K; Mixing Ratios: 5.07% NH, 85.56% H, 9.37% He). Note that these three theoretical computations were made using the same techniques used for the 7.5-9.3 mm calculation. This result is especially significant in that it contradicts the suggestion by de Pater and Massie (1985) that ammonia opacity at wavelengths shortward of 7 mm must be substantially greater than indicated by the modified Ben-Reuven lineshape. Instead it suggests an ammonia abundance distribution different than that proposed, <u>or</u> the presence of other millimeter-wave absorbing constituents, such as was suggested by Bézard (1983).

Our preliminary results at 94 GHz are also significant in that they are not consistent with the Zhevakin-Naumov lineshape, and therefore, confirm the suggestion by Spilker and Eshleman (1988) that a further modification to Ben-

Reuven lineshape best describes the microwave absorption spectrum of NH_3 under Jovian conditions. However, it should be noted that this only applies at pressures of 2 Bars or greater. At pressures well below 2 Bars, it is expected that the absorption of NH_3 will revert to that computed using the Van Vleck-Weisskopf formulation, which will be especially noticeable at frequencies far from 1-2 cm inversion resonances. Therefore, we hope to be able to characterize this transition from the modified Ben-Reuven lineshape to the Van Vleck-Weisskopf lineshape by further study of the 94 GHz opacity of NH_3 (in an H_2/He atmosphere) in the 1 to 2 Bar pressure range.

V. OBSERVATIONAL AND INTERPRETIVE STUDIES

As described in the previous Annual Status Report for Grant NAGW-533 (February 1, 1987 through January 31, 1988), studies of our recent measurements of the 1.35 to 3.6 cm emission from Venus have suggested that long term temporal and/or significant spatial variations in the abundance of SO_2 and gaseous H_2SO_4 may occur immediately below the main cloud layer (48 km and below). Our observation, which was predominantly of equatorial and mid-latitude regions of Venus, indicated a significantly lower SO_2 abundance than was measured in 1978 by the Pioneer-Venus Sounder Probe, and a lower average abundance of gaseous H_2SO_4 than would have been inferred from earlier Pioneer-Venus radio occultation studies of subcloud opacity at 13 cm. Some or all of this difference may be due to spatial variations in the subcloud H_2SO_4 abundance since most of the early Pioneer-Venus results were for polat latitudes (Cimino, 1982). Similarly, our results may be consistent with the earlier equatorial 13 cm radio occultation opacity measurements made with the Mariner 10 spacecraft (Lipa and Taylor, 1979), where the peak opacity would

correspond to a very large abundance of gaseous H_2SO_4, but the average subcloud opacity was significantly lower.

One important tool for evaluating these effects is the reduction of the microwave data from the 1986-87 Pioneer-Venus radio occultation measurements. This data was taken over a wide range of latitudes and could be critical for determining whether temporal variations or spatial variations in gaseous H_2SO_4 abundance could be occurring. Working with Dr. Arvydas J. Kliore (P-V Radioscience Leader), our group has obtained the currently unreduced data and (working at JPL) begun reducing the data to obtain absorptivity profiles for the 1986-87 epoch.

Over the next year, we will reduce data obtained from the Fall 1986/ Winter 1987 Pioneer-Venus Radio Occultation Observations. Since the initial conversion from amplitude and doppler (frequency) data to refractivity and absorptivity profiles can be most efficiently completed at JPL, we have made arrangements to send graduate students to JPL for this activity. Support for travel and student salaries for the reduction effort at JPL has been obtained from the Pioneer-Venus Guest Investigator Program.

After the initial reduction, we hope to have dependable 13 cm wavelength refraction and absorption profiles for a range of altitudes in the Venus atmosphere reaching down to 38 km and for latitudes ranging form equatorial to polar. Figure 7 shows a preliminary 13 cm absorptivity profile derived from radio data obtained during the entry occultation of Orbit 2801 on August 6, 1986. (Note: This is the first such absorptivity profile which has been derived since Orbit 358 - November 28, 1979). This occultation probed the Venus atmosphere at 52°N latitude and the ray path traversed mainly the night side of the planet. For this orbit, the spacecraft signal was only receivable

at the Goldstone DSS-14 receiver down to a periapsis altitude of 43.7 km before receiver lock was lost. (This assumes a planetary radius of 6052 km.) It is hoped that other orbits may be found which probe deeper into the atmosphere before loss of signal, but because the Pioneer-Venus steerable antenna no longer tracks the limb of the planet (the direction the radio ray travels back to earth) during the occultation, the resulting lower signal level may prevent probing deeper than the 40 km altitude.

To show the usefulness of the 13 cm opacity data for inferring the nature of the gaseous H_2SO_4 abundance, we compare in Figure 8 the measured absorptivity profile from orbit 2801N with that absorptivity which would result from a saturation abundance of gaseous H_2SO_4 (from Steffes, 1985) in the 43 to 55 km altitude range. It can be seen that for altitudes in the 49 to 51 km altitude range (the nominal altitude range of the Venus lower cloud - see Ragent and Blamont, 1980), absorptivity values close to those caused by a saturation abundance of gaseous H_2SO_4 are seen. At lower altitudes, most values for absorptivity are below those caused by a saturation abundance. It should be noted that error bars for this preliminary absorptivity data have not yet been computed, but are expected to be on the order of ±0.001 dB/km (±0.00023 km^{-1}).

Figure 9 shows the full extent to which application of our laboratory results can be carried. The abundance of gaseous H_2SO_4 (derived from the absorptivity profile in Figure 5 by using laboratory results from Steffes, 1985) is plotted as a function of altitude, along with a plot of the saturation abundance of gaseous H_2SO_4, for comparison. As our work in the Pioneer-Venus Guest Investigator Program yields more absorptivity profiles for a wide range of locations in the Venus atmosphere, we hope to be able to well

characterize the abundance, structure, and spatial variations of gaseous H_2SO_4 in the Venus atmosphere. We also hope to make comparative studies with earlier radio astronomical and radio occultation measurements in order to detect possible temporal variations in H_2SO_4 abundance and structure.

Also, our new results for the 3.2 mm opacity of ammonia under Jovian conditions holds promise for new interpretive studies and possibly some new observational studies of the millimeter-wave emission spectra from the outer planets. We include further discussion of this in the attached proposal.

VI. PUBLICATIONS AND INTERACTION WITH OTHER INVESTIGATORS

In the first half of the current grant year, a paper was completed and accepted for publication in Icarus, describing results and applications of some experiments performed during the previous year of Grant NAGW-533 (Jenkins and Steffes, 1988a). This paper describes laboratory measurements of the microwave absorption of methane (CH_4) and water vapor (H_2O) under simulated Jovian conditions. The paper also concludes, that based on these laboratory results, neither methane nor water vaport can be responsible for the excess microwave opacity detected at wavelengths between 10 and 20 cm in the atmosphere of Jupiter. This supports the presence of an ammonia abundance which exceeds solar abundance by a factor of 1.5 in the 2 to 6 Bar levels in Jupiter's atmosphere.

In addition, as discussed in Section I, we completed a paper describing observations and interpretive studies of the 1.3 to 3.6 cm Venus emission spectrum (Steffes et al., 1988). Likewise, a paper describing the results and applications of the laboratory measurements of the millimeter-wave opacity of ammonia described in Section IV has been submitted for publication in Icarus

(Joiner _et al._, 1988a). We also submitted updated summaries of our most recent laboratory measurements for inclusion in the twenty-second issue of the _Newsletter of Laboratory Spectroscopy for Planetary Science_.

We attended the 20th Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society the week of October 30 through November 4. In addition to presenting our work involving the Venus studies (Jenkins and Steffes, 1988b), our latest laboratory results for the millimeter-wave opacity from ammonia were presented by GRA Joanna Joiner (Joiner _et al._, 1988b -- abstract attached).

In addition to the observations of Venus and analysis work conducted jointly with Dr. Michael J. Klein of JPL, we have also worked with Dr. Michael A. Janssen of JPL regarding models for the Venus atmosphere, interpretation of microwave emission measurements, and theoretical models for the absorption spectrum of H_2SO_4. A presentation of our laboratory results for simulated Venus and Jovian atmospheres was given at JPL on September 9, 1988. We have also worked with Dr. Arvydas J. Kliore of JPL on the reduction and interpretation of data from recent Pioneer-Venus Radio Occultation Studies as part of our involvement in the Pioneer-Venus Guest Investigator Program. More informal contacts have been maintained with groups at the California Institute of Technology (Dr. Duane O. Muhleman and his students, regarding interpretation of radio astronomical measurements of Venus and the outer planets), at the Stanford Center for Radar Astronomy (V. R. Eshleman, G. L. Tyler, and T. Spilker, regarding Voyager results for the outer planets, and laboratory measurements), and at JPL (Drs. Robert Poynter and Samuel Gulkis, regarding radio astronomical observations of the outer planets and Venus). We have also worked with Dr. Imke de Pater (University of California-Berkeley) by using our

laboratory measurements of atmospheric gases in the interpretation of radio astronomical observations of Venus and the outer planets. We have also studied possible effects of the microwave opacity of cloud layers in the outer planets atmospheres. In this area, we have worked both with Dr. de Pater and with Dr. Paul Romani (NRC Associate, Goddard SFC).

Dr. Steffes has also been active in the review of proposals submitted to the Planetary Atmospheres Program at NASA (both as a "by-mail" reviewer and as a member of both the March 1988 and September 1988 review panels) and as a reviewer of manuscripts submitted to Icarus and the Journal of Geophysical Research, for which Dr. Steffes is an Associate Editor. We have also continued to serve the planetary community through the distribution of reprints of our articles describing our laboratory measurements and their application to microwave and millimeter-wave data from planetary atmospheres. The results of these measurements have been used in the mission planing for radio and radar systems aboard the Galileo and Magellan missions, and more recently, for proposed experiments for the Cassini mission. Dr. Steffes also participated as a member of the International Jupiter Watch (IJW) Laboratory/Theory Discipline Team. Another source of close interaction with other planetary atmospheres principal investigators has been Dr. Steffes' membership in the Planetary Atmospheres Management and Operations Working Group (PAMOWG). Travel support for Dr. Steffes' attendance at PAMOWG meetings, as well as the November AAS/DPS meeting, has been provided by Georgia Tech in support of Planetary Atmospheres Research. Also in support of Planetary Atmospheres Research, Georgia Tech provided $2,000 for required repairs and maintenance to the ultra-cold freezer system used in the outer planets atmospheric simulator.

As in the past, we have maintained contact with members of the Georgia congressional delegation, keeping them aware of our work and aware of our continued support for the solar system exploration program. We were especially pleased with the support received from Senator Wyche Fowler for the CRAF/Cassini "new start," after briefing his staff on this issue.

VII. CONCLUSION

In the first half of this grant year, we continued to conduct laboratory measurements of the millimeter-wave properties of atmospheric gases under simulated conditions for the outer planets. Significant improvements in our system made it possible to accurately characterize the opacity from gaseous NH_3 at longer millimeter-wavelengths (7.5 to 9.3 mm) under simulated Jovian conditions. In the second half of this grant year, we extended such measurements to even shorter millimeter-wavelengths (3.2 mm). The preliminary results of these measurements have been significant in that they seem to indicate that the large opacities predicted by a number of workers at these wavelengths are indeed incorrect and that a form of the modified Ben-Reuven formalism for computing the millimeter-wave opacity from ammonia is correct. In the next nine months of the grant, we will complete this study. We will also pursue further analysis and application of our laboratory results to microwave and millimeter-wave absorption data for the outer planets, such as results from Voyager Radio Occultation experiments and earth-based radio astronomical observations. We also intend to pursue the anlaysis of available multi-spectral microwave opacity data from Venus, including data from our most recent radio astronomical observations in the 1.3 to 3.6 cm wavelength range and newly obtained Pioneer-Venus Radio Occultation measurements at 13 cm, using our laboratory measurements as an interpretive tool.

VIII. REFERENCES

Berge, G. L. and Gulkis, S. (1976). Earth-based radio observations of Jupiter: Millimeter to meter wavelengths. In Jupiter (T. Gehrels, Ed.), pp. 621-692, Univ. of Arizona Press, Tucson.

Bézard, B., A. Marten, J. P. Baluteau, D. Gautier, J. M. Flaud, and C. Camy-Peyret (1983). On the detectability of H_2S in Jupiter, Icarus 55, 259-271.

Cimino, J. B. (1982). The composition and vertical structure of the lower cloud deck on Venus. Icarus 51, 334-357.

Collin, R. E. (1966). Foundations for Microwave Engineerign. McGraw-Hill, New York.

de Pater, I. (1986). Jupiter's zone-belt structure at radio wavelengths. II. Comparison of observations with model atmosphere calculations. Icarus 68, 344-365.

de Pater, I. and Massie, S. T. (1985). Models of the millimeter-centimeter spectra of the giant planets. Icarus 62, 143-171.

Jenkins, J. M. and P. G. Steffes (1988a). Constraints on the microwave opacity of gaseous methane and water vapor in the Jovian atmosphere. Icarus, in press.

Jenkins, J. M. and P. G. Steffes (1988b). Preliminary results for 13-cm absorptivity observed during Pioneer-Venus radio occultation season #10 (1986-87). Bull. Amer. Astron. Soc. 20, 834.

Joiner, J., J. M. Jenkins, and P. G. Steffes (1987). Laboratory measurements of the opacity of gaseous ammonia (NH_3) in the 7.3-8.3 mm (36-41 GHz) range under simulated conditions for Jovian atmospheres, Bull. Amer. Astron. Soc. 19, 838. Presented at the 19th Annual Meeting of the Division of Planetary Sciences of the Amerian Astronomical Society, Pasadena, California, November 11, 1987.

Joiner, J., P. G. Steffes, and J. M. Jenkins (1988a). Laboratory measurements of the 7.5-9.38 mm absorption of gaseous ammonia (NH_3) under simulated Jovian conditions. Submitted to Icarus.

Joiner, J., J. M. Jenkins, and P. G. Steffes (1988b). Millimeter-wave measurements of the opacity of gaseous ammonia (NH_3) under simulated conditions for the Jovian atmosphere. Bull. Amer. Astron. Soc. 20, 867.

Lipa, B. and G. L. Tyler (1979). Statistical and computational uncertainties in atmospheric profiles from radio occultation: Mariner 10 at Venus. Icarus 39, 192-208.

Morris, E. C. and Parsons, R. W. (1970). Microwave absorption by gas mixtures at pressures up to several hundred bars: I. Experimental technique and results. Aust. Journal of Physics 23, 335-349.

Ragent, B. and J. Blamont (1980). The structure of the microwave opacity and vapor pressure of sulfuric acid under simulated conditions for the middle atmosphere of Venus. Icarus 64, 576-585.

Spilker, T. R. and V. R. Eshleman (1988). A new formalism for predicting microwave absorption by ammonia based on laboratory measurements under varying conditions. Bull. Amer. Astron. Soc. 20, 867.

Steffes, P. G. (1985). Laboratory measurements of the microwave opacity and vapor pressure of sulfuric acid under simulated conditions for the middle atmosphere of Venus. Icarus 64, 576-585.

Steffes, P. G. (1986). Evaluation of the microwave spectrum of Venus in the 1.2 to 22 centimeter wavelength range based on laboratory measurements of constituent gas opacities. Astrophysical Journal 310, 482-489, November 1, 1986.

Steffes, P. G. and J. M. Jenkins (1987). Laboratory measurements of the microwave opacity of gaseous ammonia (NH_3) under simulated conditions for the Jovian atmosphere. Icarus 72, 35-47.

Steffes, P. G., M. J. Klein, and J. M. Jenkins (1988). Observation of the microwave emission spectrum of Venus from 1.3 to 3.6 cm. Submitted to Icarus.

Wrixon, G. T., W. J. Welch, and D. D. Thornton (1971). The spectrum of Jupiter at millimeter wavelengths. Astrophys. J. 169, 171-183.

Zhevakin, S. A. and A. P. Naumov (1967). Coefficient of absorption of electromagnetic waves by water vapor in the range 10 microns - 2 cm. (Soviet) Academy of Science: Atmospheric and Oceanographic Physics, 3, 674-694.

IX. KEY FIGURES

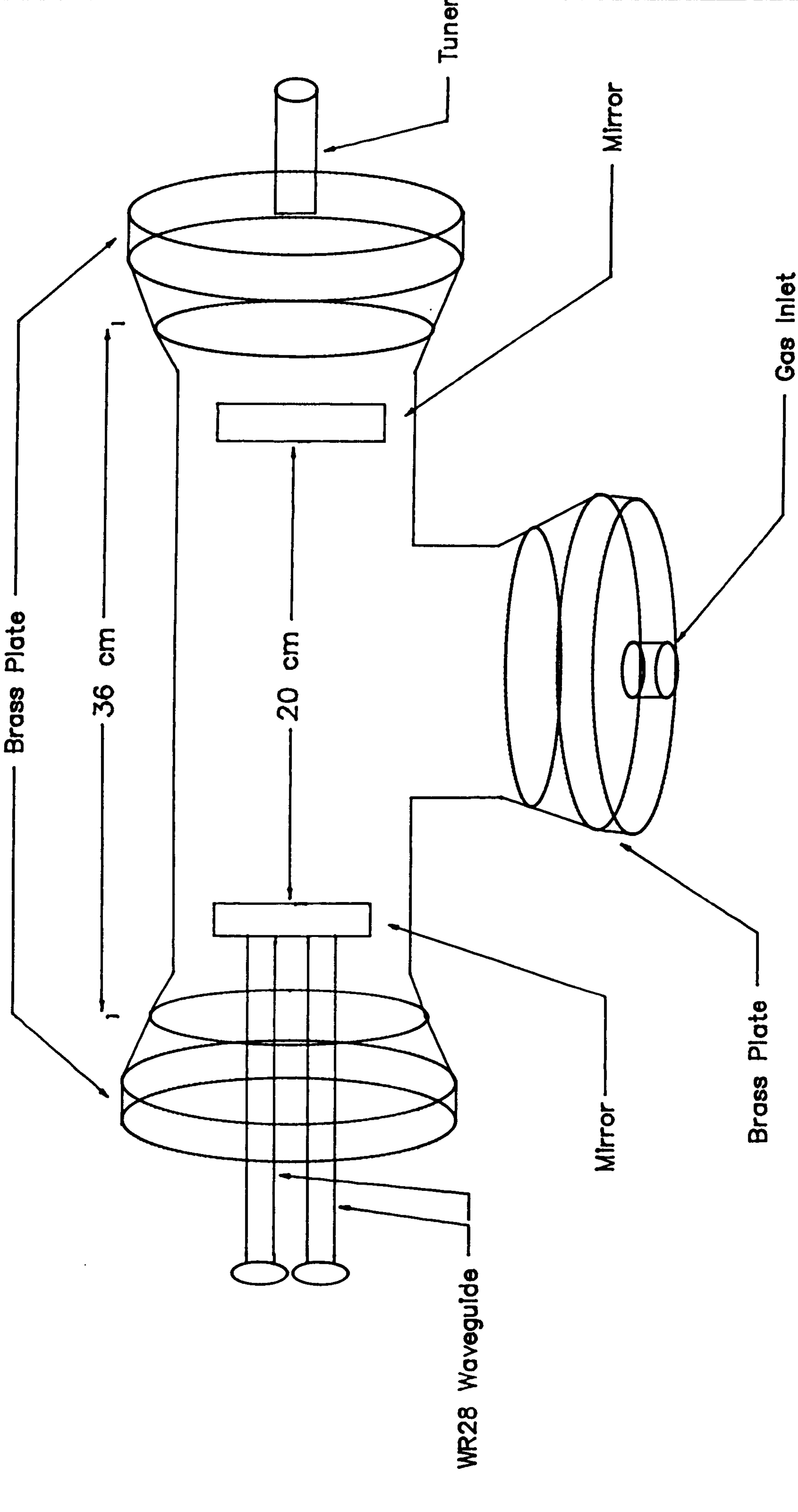


Figure 1: Diagram of Fabry–Perot Resonator

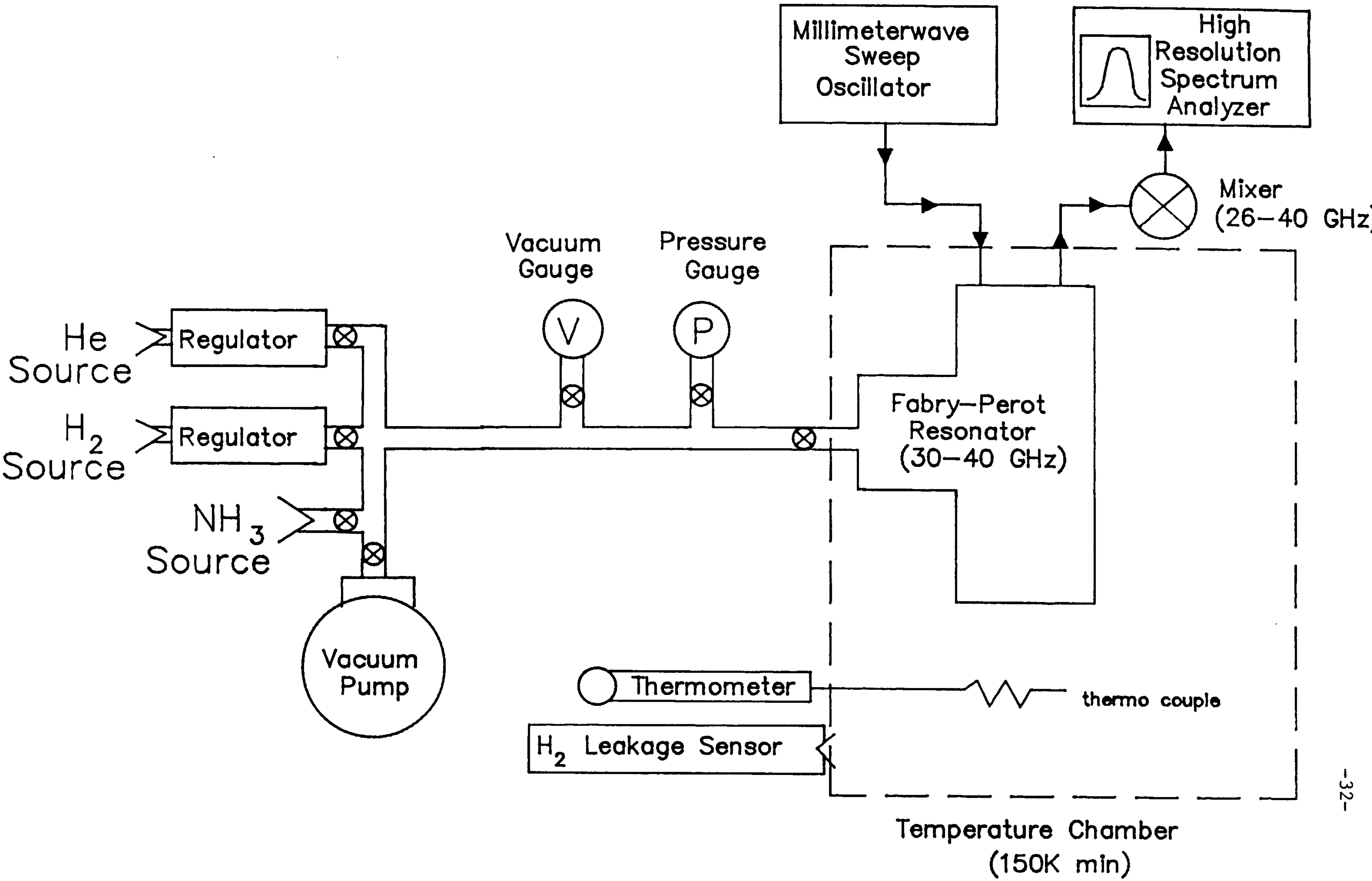
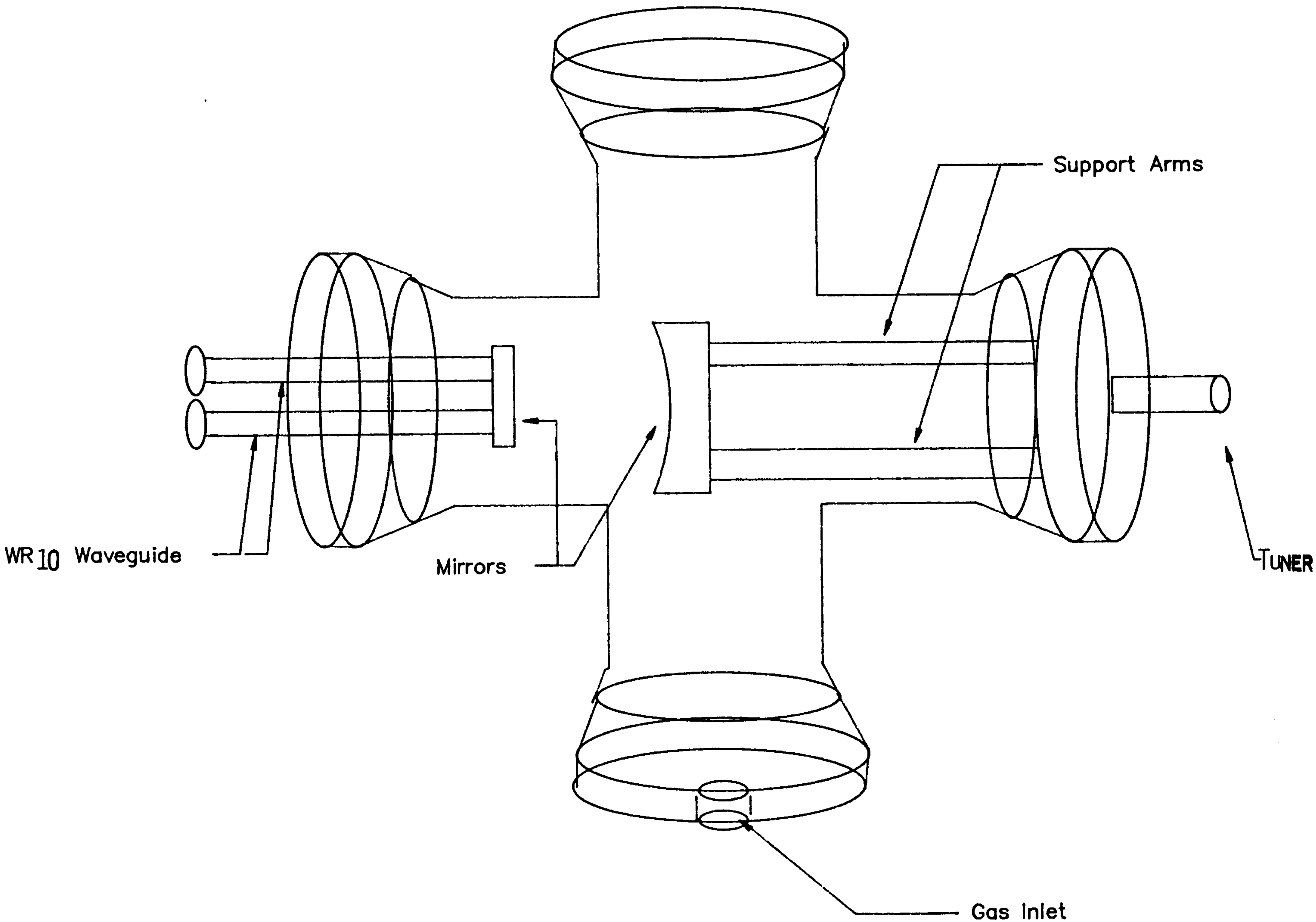


Figure 2: Block Diagram of Atmospheric Simulator (30–40 GHz)

FIGURE 3: DIAGRAM OF FABRY-PEROT RESONATOR (94GHz)



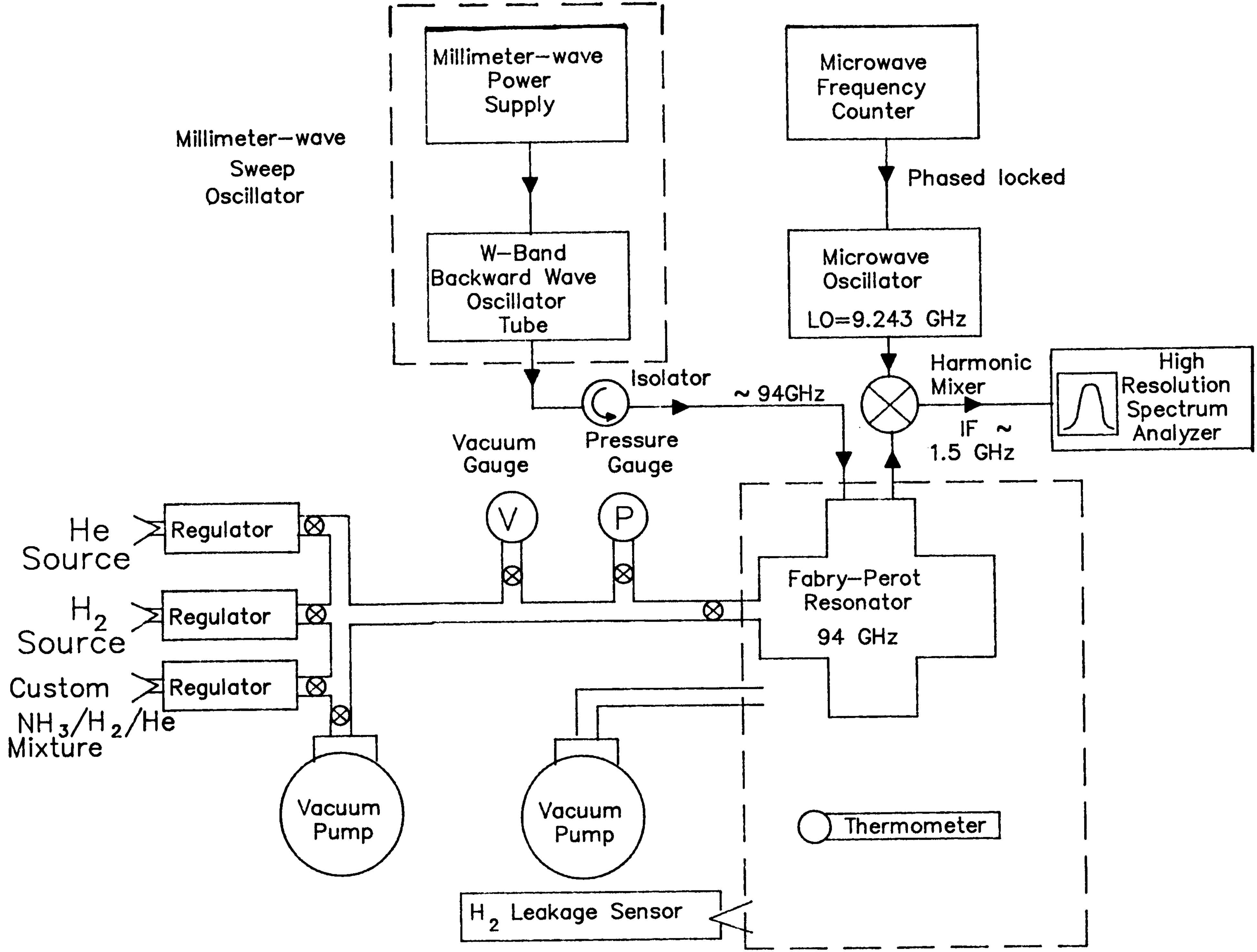
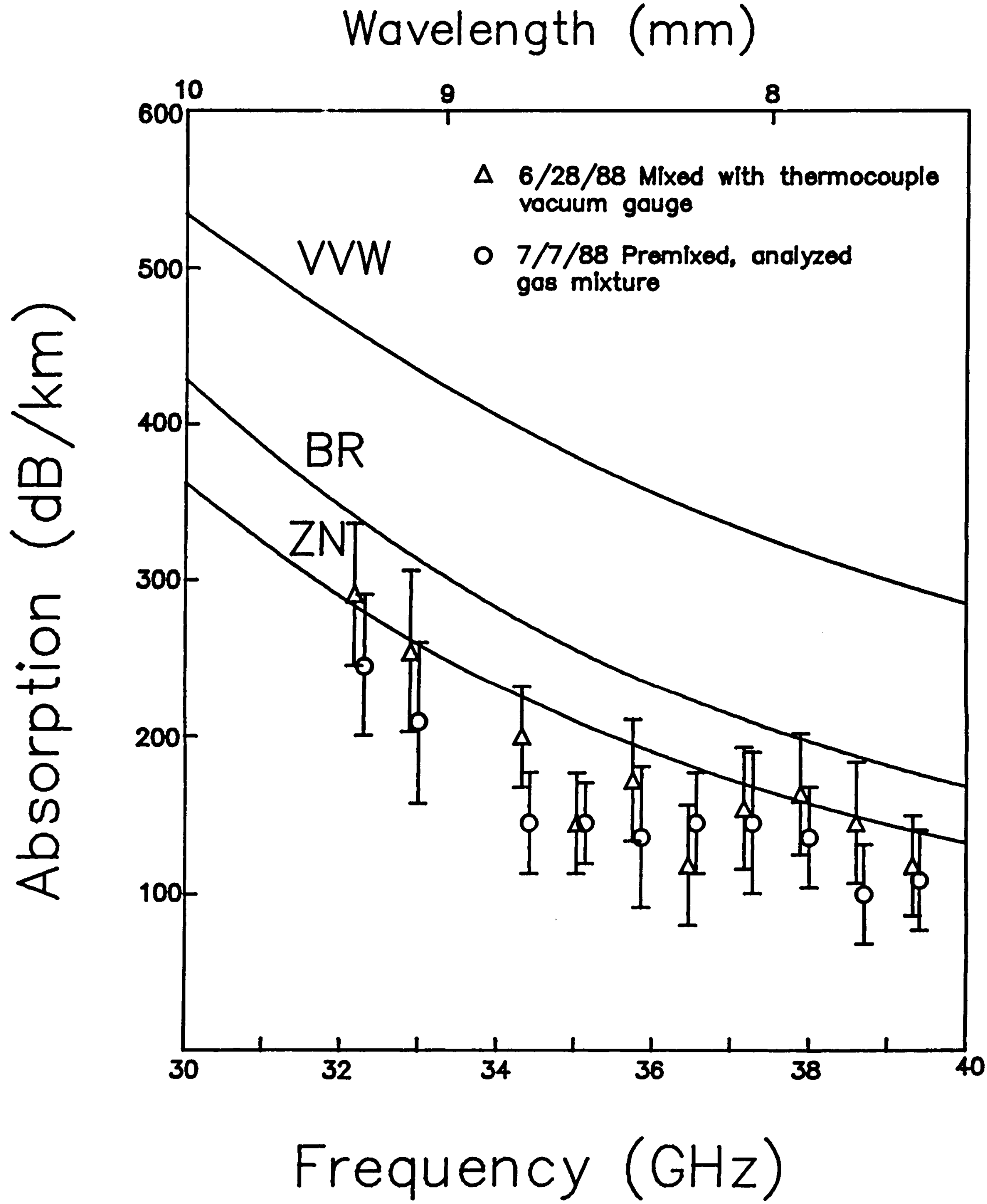


FIGURE 4:
BLOCK DIAGRAM OF ATMOSPHERIC SIMULATOR (94 GHZ)

FIGURE 5: Absorption of NH_3 in a 88.34% H_2, 9.81% He, 1.85% NH_3 mixture (Mixing ratio: 0.0185±0.0005) Pressure: 2 atm. Temp: 203K



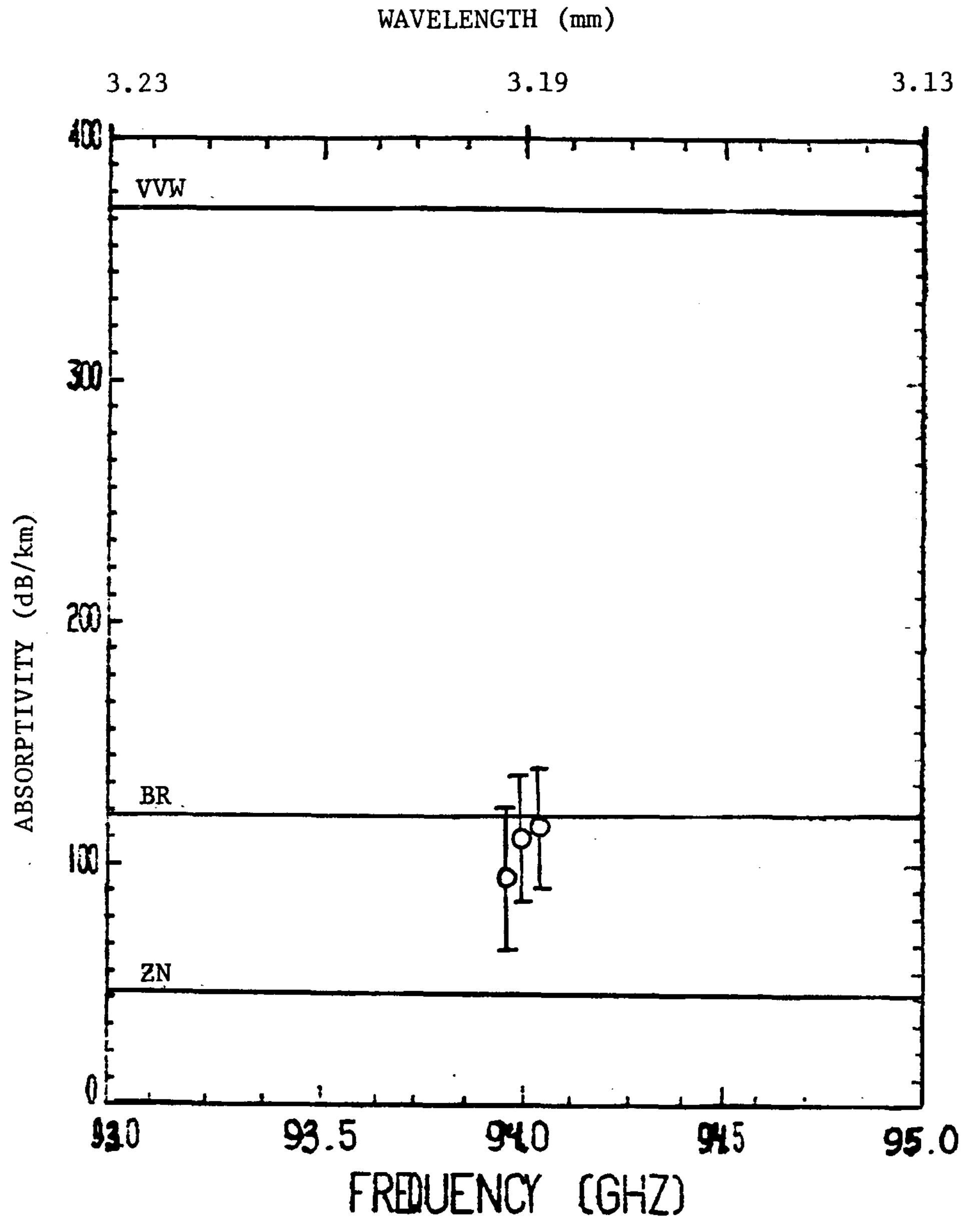


Figure 6: Absorptivity of gaseous mixture (5.07% NH_3, 9.37% He, and 85.56% H_2) under simulated Jovian conditions (Total pressure: 2 Bars, Temperature: 210 K). Shown for comparison (horizontal lines), are the theoretically computed values from the Van Vleck-Weisskopf formalism (top line), the modified Ben Reuven formalism (middle line), and the Zhevakin-Naumov formalism (lower line).

Figure 7: Absorptivity profile (preliminary) derived from 13-cm radio data (2.293 GHz) obtained during the entry occultation of Pioneer-Venus Orbit 2801 (August 6,1986). Periapsis latitude is 52°N.

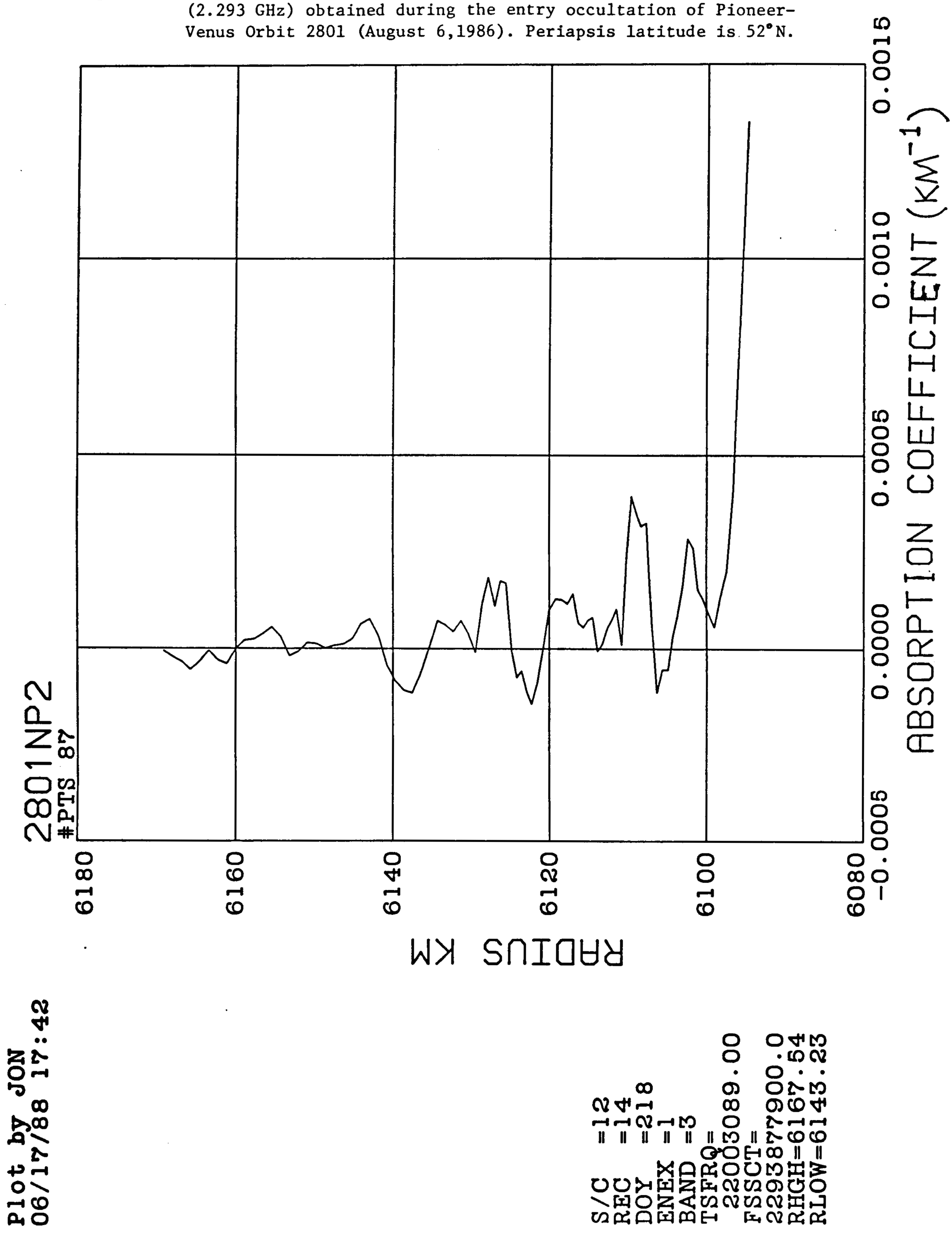


Figure 8 : Comparison of absorptivities measured with radio occultation technique (circular points -- from Pioneer-Venus Orbit 2801-entry occultation) with absorptivity which would result from saturation abundance of H_2SO_4 (from Steffes, 1985). The absorption coefficient scale is logarithmic (exponents of 10). All measurements were made at the 13-cm wavelength (2.293 GHz).

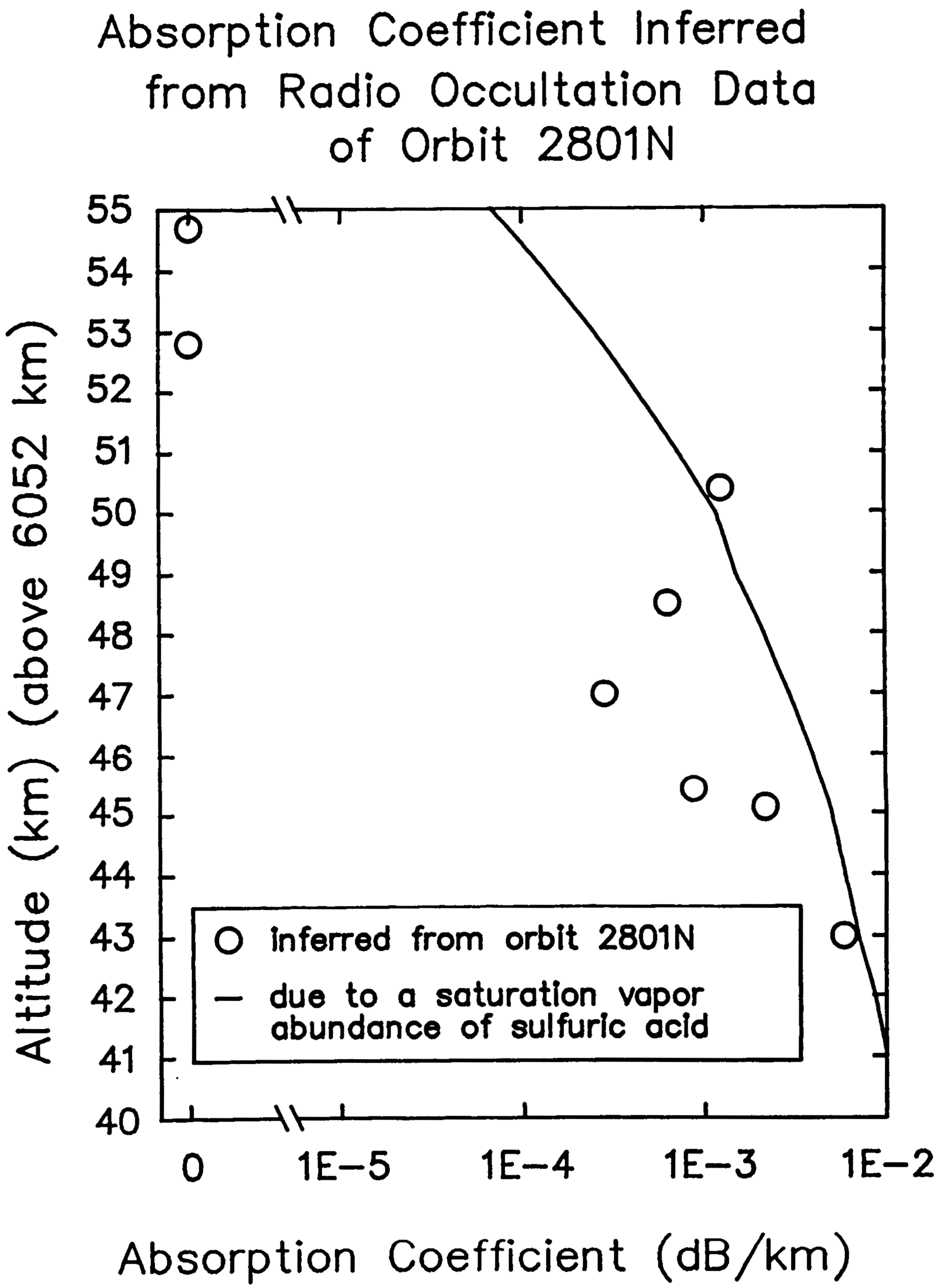
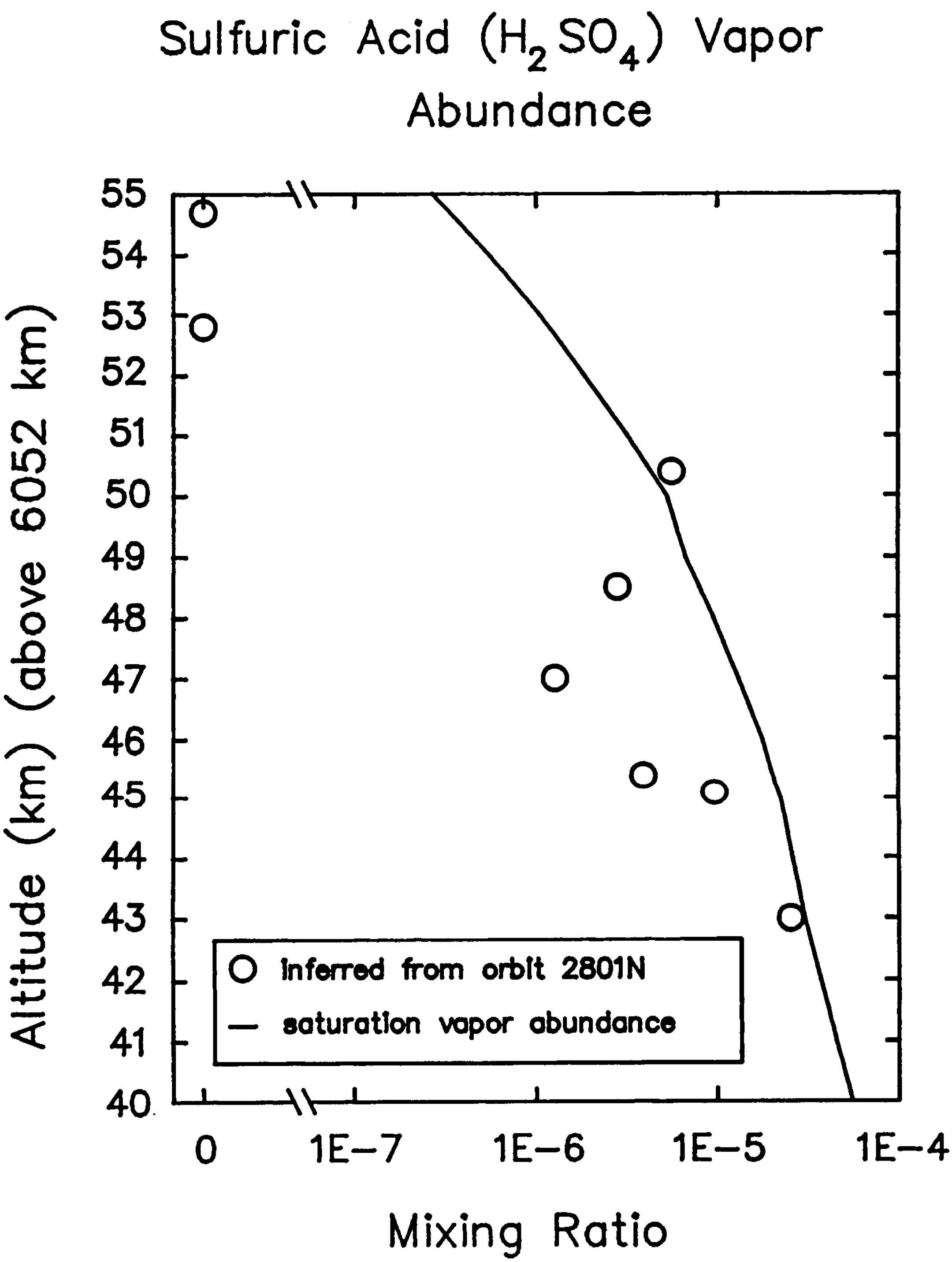


Figure 9: Abundances of gaseous H_2SO_4 inferred from Pioneer-Venus 13-cm absorptivity profiles (circular points) compared with the saturation abundance profile of gaseous H_2SO_4 (from Steffes, 1985). The mixing ratio scale is logarithmic (exponents of 10).



X. APPENDIX

Millimeter-Wave Measurements of the Opacity of Gaseous Ammonia (NH_3) Under Simulated Conditions for the Jovian Atmosphere

J. Joiner, J.M. Jenkins, P.G. Steffes (Georgia Institute of Technology)

Last year, preliminary results of laboratory measurements of the opacity of gaseous ammonia (NH_3) from 32-40 GHz (7.5 - 9.3 mm) in an H_2/He atmosphere were presented. These measurements were conducted at a pressure of two atmospheres, a temperature of 203K, and a mixing ratio of 0.0185. However, due to large uncertainties, the results were inconclusive as to which theoretical lineshape best described the observed behavior under these conditions. Over the past year, we have been able to significantly reduce the uncertainties in these measurements. Our final results show that the Zhevakin-Naumov lineshape best describes the absorption of ammonia under these conditions between 32 and 40 GHz. Thus, both the Ben-Reuven lineshape and the VanVleck-Weisskopf overstate the absorption due to ammonia in this region. We also plan to make similar measurements at 94 GHz (3.2mm), where several radio emission studies have been made and even larger variations from theoretically derived lineshapes are expected.

This work was supported by the Planetary Atmospheres Program of the National Aeronautics and Space Administration under Grant NAGW-533.

ORIGINAL PAGE IS OF POOR QUALITY

Division for Planetary Sciences - Austin meeting

American Astronomical Society

Date Submitted ______

PAPER READ BY Joanna Joiner
(Please Print)

☒ Oral Poster ☐

SPECIAL INSTRUCTIONS:

Georgia Tech
Author's Address — *Print*
P.O. Box 34362
Atlanta, GA 30332

Joanna Joiner
Signature of Author

Signature of Introducing Member, if Author is a Non-Member

THE INFORMATION BELOW MUST BE PROVIDED UNLESS PAYMENT IS ENCLOSED.

We agree to pay **$30** in partial support of the publication of the abstract i the BULLETIN OF THE AMERICAN ASTRONOMICAL SOCIETY.

Date: 7/29/88

Georgia Institute of Techn
Institution to be billed

Joseph F. Jackson
Signature of Authorized Agent

Accounts Payable
Room 50, Knowles Bldg.

P.O. # 210920126
(Payable to American Institute of Physics)

Atlanta, GA 3033
Address

IMPORTANT: If your institution requires a purchase order to cover our billing (and all branches o government do), please have your purchasing agent include in the order the name of the journa title and author(s), and identity of the Meeting at which the abstracted paper was presentec **Purchase orders should be made out to the order of: American Institute of Physics, Publicatio Charge and Reprint Section, 335 East 45th St., New York, N.Y. 10017**, as the Institute will bill yo on our behalf. **Make all checks payable to the American Institute of Physics.** Purchase Order should not contain shipping instructions as no reprints are offered for shipment; order is for publishing charge only.

SUBMIT ABSTRACT TO: E. S. Barker/DPS
McDonald Observatory
University of Texas at Austin
RLM 15.308
Austin, TX 78712-1083

FOR EDITORIAL USE ONLY

BAAS VOL. ______, NO. ______, 198 ______